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A.U.W.E. Tech Note 151/64

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ANALYSIS OF CANADIAN TRIALS OF THE PROXIMITY FUZE FOR PROJECT INSIGHT. (C)

BY

A. BUTTERWORTH.

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A.U.W.E. Technical Note 151/64
April 1964

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A. Butterworth

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PRÉCIS

1. Full-scale trials of the operation of a magnetic influence fuse mounted in an A/S mortar have been performed by the Canadians, with the support of A.U.W.E., using a submerged submarine target in Scottish waters.

2. H.M. S/M TAPIR, a submarine of 1300 tons displacement, was used as the target in these trials. The submarine was kept fixed heading either south or east at a nominal depth of 100 feet below the surface, while the projectile was dropped down a vertical tube placed at given positions at the side of the submarine. Trials were conducted first with the submarine in its natural stable magnetic condition and then immediately after being wiped.

3. This report is a critical analysis of the trials, the objects of which were to investigate the anomaly field round the submarine and to determine the position of firing of the fuse with respect to the submarine.

RESULTS

4. The results of the analysis show that there are a number of sources of error in the method of recording the field anomaly round the submarine.

5. In spite of these errors, the results confirm that the field round the submarine is in good agreement with theory in the case of an untreated submarine.

6. In the case of the wiped submarine, the complicated nature of the field anomaly made it virtually impossible to deduce the true field anomaly in the presence of the various errors.

7. The firing of the fuze occurred at or near the expected position on a large proportion of the drops while the limiting signal for firing appeared to be about 10 milligauss.

RECOMMENDATIONS

8. For any future trials that are considered desirable the results lead to the following recommendations.

9. Methods of ascertaining the position of the tube with respect to the submarine must be improved.

10. The stability of the recording equipment should be increased to reduce drift and it should be fitted with variable sensitivity for recording large fields.

11. The equipment should be calibrated immediately prior to a drop, i.e. by the application of a known field.

12. The start of a drop should be clearly indicated on the trace, which could be done conveniently by means of the same known field.

13. The finish of a drop should also be clearly indicated.

14. Accurate measurement of heading and depth of the submarine should be made at the time of a drop.

INTRODUCTION

15. Trials of a magnetic proximity fuze in an A/S projectile were conducted during August and September of 1963 against a submarine target. The submarine endeavoured to keep at a fixed depth below the surface, while an A/S projectile was dropped down a vertical tube placed at various positions round the submarine. A recorder was used to record the magnetic field anomaly of the submarine and the times of operation of the fuze. For the first part of the trials the submarine was in its natural stable magnetic condition as measured over a degaussing range before the trials started. After this first part the submarine was checked over the range and then wiped to give minimum vertical field as measured over the range for the second part of the trials, after which the submarine was again checked over the range. For both parts of the trials the submarine was first oriented to head south and then east.

16. The object of the trials was to investigate the anomaly field of the submarine and to determine the position of firing of the fuze with respect to the submarine. A superficial examination of the results indicated that the lateral ranges for fuze operation appeared to be adequate on the port side of the submarine on both headings with the submarine in its natural state, although somewhat less than expected from the readings obtained over the degaussing range. Furthermore it appeared that ranges on the starboard side, which were obtained only when the submarine was heading east, were considerably less than expected. The ranges for a wiped submarine also appeared to be less than expected.

17. A more detailed examination of the trial results has been made as described in this paper, and it is concluded that there must have been considerable inaccuracies in the measurement of the distance between the submarine and the dropping tube.

CALCULATION OF THE FIELD ANOMALY OF AN UNTREATED SUBMARINE

18. The field anomaly of an untreated submarine can be calculated approximately by assuming that the submarine can be represented as a spheroid, the magnetisation constants of which can be obtained from D.G. range records. The case of a wiped submarine has been treated in detail in U.C.W.E. Informal Report No. 1649/55 and A.U.W.E. Technical Note 90/62. For the purpose of this present analysis the methods employed in these two references have been used to compute the required anomaly field round the submarine in its natural condition, the vertical magnetisation constant being deduced from the readings over the D.G. range and the horizontal constants being taken as the same as in A.U.W.E. Technical Note 90/62. In this way the field anomaly down vertical tubes at the side of the submarine in a field of 500 milligauss (70° Dip) has been computed for the positions illustrated in Figure 1. The results are plotted in Figure 2 for a 1300 ton submarine heading south and in Figure 3 for the same submarine heading east. The computations have been made for positions 50 feet from the centre line of the submarine, but approximations for closer distances can be obtained by scaling down distances proportionally and field in inverse proportion to the square of the distance.

COMPARISON BETWEEN MEASURED AND CALCULATED FIELD SIGNALS

19. When a comparison is made between the measured and calculated field curves of an untreated submarine it is found that agreement between the

two is fairly good for some of the drops, but in general the agreement is much lower than expected. The form of the field curves, i.e. a large reduction in field at the side of the submarine and an increase above the submarine, is as expected confirming that the submarine is mainly vertically magnetised. The main discrepancies lie in the magnitude of the reduction and the distance over which the reduction extends. The measured field is usually much less than the computed one by a factor of about 4 in a large number of cases and as much as 15 at the most. Suggested reasons for these discrepancies are discussed later in detail under separate headings.

20. The field round a wiped submarine is much more complicated and will lie somewhere between the two cases considered in A.U.W.E. Technical Note 90/62. No attempt has been made in this report to compare theory with measurement for a wiped submarine, because this is difficult under ideal conditions and is not considered possible until the discrepancies in the untreated state are cleared up.

DISCUSSIONS OF SOURCES OF ERROR

21. The various likely sources of error are considered individually bearing in mind that the magnitude of the error in a number of cases amounts to as much as a reduction of 4 to 1 in field, which is equivalent to an increase in distance of 2 to 1.

Fields from Other Sources

22. In order to check that the measured field arises only from the presence of the submarine, measurements of field were made down the tube with the submarine absent. Although a preliminary investigation indicated that the tube was magnetically clean, it was found during the trials that signals were obtained at the top of the tube which were not consistent with the presence of the submarine. An investigation of these signals, which are referred to as anomaly signals, was undertaken after the main trials had finished. For this purpose the magnetic field down the tube was measured by means of the fuze magnetometer and by a nuclear precession magnetometer. Very good agreement between the two was obtained and the results for the three relevant conditions are plotted in Figure 4. These fields are obtained by averaging the two magnetometer readings, the difference between which did not exceed half a milligauss.

23. Errors from the presence of this anomaly arise because the fuze magnetometer zero is difficult to ascertain when the equipment is set up in the presence of the anomaly. Figure 5 is a typical recording of field against distance dropped after subtraction of the high-frequency background noise arising in the recording equipment. Since the recorder really records frequency against time the trace before the projectile starts dropping checks that the amplifier is not drifting. Again the trace after the 150-foot depth, when the projectile is pulled up, checks amplifier drift, movement of submarine and amplifier overshoot. The dotted curve is the submarine signal obtained by subtracting the anomaly. It will be seen that the anomaly field at the start is negligible in this case, being less than a milligauss. Figure 6, which shows a small submarine signal near the stern, is a case where the anomaly signal and submarine signal are well separated. The anomaly signal at the start of the drop is appreciable, but it is clearly shown and can be allowed for. In general very little difficulty arises from the presence of the anomaly and errors from this source are negligible.

Submarine Signal at Start of Drop

24. The length of the tube was a compromise between the use of a long tube to get away from the submarine signal at the start of the drop and a short tube to ease the problem of knowing where the submarine is situated. The choice of a 150 foot tube was to enable the submarine to operate at a depth of 110 feet, which was the limit of the submarine's accurate depth indicator. Under these conditions the submarine signal will not produce appreciable errors, because even at the limit of fuze operation errors in estimating the submarine signal cannot be greater than 4 milligauss in 10 milligauss.

Equipment Drift

25. Examination of the results shows that the field trace can drift when the projectile is stationary. The cause of this drift could be movement of the submarine with respect to the projectile, drift of the fuze amplifier output or drift of the backing off voltage used in the recording circuitry. Movement of the submarine is estimated to produce too small a drift and the fuze circuitry is well stabilised, so that the most likely cause is drift of the backing off voltage.

26. Figure 7 illustrates a drop during which the drift was particularly bad. The field zero at the start of the run is obtained by subtracting the known anomaly field and the estimated submarine field. If the amplifier then continues to drift at the same rate, the zero line will be approximately parallel to the recording trace before the run started, while if the amplifier stopped drifting the zero line would be horizontal. These two lines are shown in Figure 7, from which it will be seen that the maximum submarine signal is either 22 or 15 milligauss depending on which zero is taken. On most of the traces the drift appears to be considerably less than this, so that an error of 7 milligauss is likely to be the maximum obtained during the trials.

Magnetometer Sensitivity

27. The fuze magnetometer and auxiliary equipment used for measuring field was not calibrated immediately prior to the drop under correct battery and temperature conditions, so that there will be errors from this source in estimating maximum submarine signals. However, when the projectile passed the tube anomaly at the start of its drop, the sensitivity of the equipment was inadvertently checked.

28. Examination of the recordings shows that the mean value of the ratio of sensitivity by anomaly to sensitivity by calibration is 0.93 with a standard deviation of 0.16.

Magnetisation of the Submarine

29. It is very improbable that the submarine could change its magnetism in its stable condition, because it was checked both before and after the trial. Furthermore it is well established that the vertical magnetisation of a vessel is large in these latitudes and is predictable from the dimensions of the vessel. The differences between a perfect ellipsoid, assumed for Figure 2 and 3, and the actual submarine are illustrated in Figure 8. It will be seen that the difference is not large under the submarine and

cannot, therefore, be large at the side. Neglecting the ends of the submarine the maximum difference between theory and practice will not exceed 25% of the theoretical value.

Position of the Submarine

30. The position of the submarine with respect to the tube appears to be the most likely source of error. The depth of the submarine, as measured by its own depth indicator, was checked by virtually suspending it from the surface on floating dans. The orientation of the submarine in the earth's field was kept fixed and checked by observation of the magnetic compass. The distance of the submarine from the tube was kept at its required value by keeping a fixed length of wire joining the two taut and at right angles to the submarine. There was no direct check on the correct operation of the fixed line. When the submarine is in its stable magnetic condition, its field is practically independent of orientation and fairly uniformly distributed along its length if not too near the end; thus the only important source of field errors is error in distance from the submarine.

31. In order to check the position of the submarine with respect to the tube the magnetic signal signature down the tube can be used to estimate both the depth of the submarine and its distance away, assuming that it is uniformly magnetised in its stable condition. The method employed is to note the maximum reading of the anomaly and then to ascertain the positions down the tube at which the field falls to half this maximum. The distance between these two positions is approximately the distance away of the submarine. A better estimate is obtained by using a correction factor depending on the orientation of the submarine. For south headings theory shows that the correction factor is not necessary, while for east headings the distance between half signals should be multiplied by 1.25 to give the distance between the centre line of the submarine and the tube. The position of maximum signal gives the depth of the submarine if the signature is symmetric about its maximum, while corrections have to be applied if not symmetric depending on the degree of asymmetry. Another method of estimating distance is to obtain it direct from the amplitude of the anomaly, which is known theoretically round the submarine at various distances from it.

32. These magnetic methods of estimating depths and distances have been applied to all reliable signatures with the submarine in its stable condition, except those near the bow or stem, and the results of this analysis are given in Table 1.

33. An examination of Table 1 shows that there is good agreement between the nominal depth of the submarine and that estimated from the field anomaly, the average difference being of the order of 8 feet.

34. With regard to distances there is good agreement between all three methods over a fair proportion of the runs, especially those on the port side, showing that the fixed line operated satisfactorily on those runs. However on the other runs, especially those on the starboard side, there is considerable discrepancy between the nominal distances and those estimated by magnetic methods, which compare well between themselves. There is therefore considerable doubt on the satisfactory operation of the fixed line, which was checked by pulling up tight on a running line until a stop was reached. It would seem from these results that for some of the runs the line operated

satisfactorily, but that the stop could not have been reached on the starboard side and possibly a few times on the port side. This may be due to some tidal conditions or to some difference in the tackle on the starboard side.

35. In view of the close agreement between the two magnetic methods of estimating distances it is considered that a reliable estimate of distance is obtained by taking the average of these two.

POSITION OF FUZE OPERATION

36. The fuze was designed to operate on a two-look principle, the first look occurring when the field reached a given value and the second look when the field had fallen by the same given amount from a maximum value. This method of operation ensured that the second look, which fired the fuze, occurred close to the position of nearest approach.

37. A study of the field traces showed that in general the fuze operated satisfactorily when subjected to the correct field changes. The appropriate look operated when the field reached a value between 5 and 10 milligauss, the higher values tending to occur when the field changes were slow. Since slow changes are associated with extreme ranges, the limit of operation of the fuze is governed by a sensitivity of about 10 milligauss. While the actual fuze operated as designed it did not always give a second look at the correct place, because it sometimes had a first look at the anomaly. There were also a few cases when a look did not appear to occur when it should have occurred, but these cases were rare and could be explained by the recording equipment failing to give an indication of a look on the trace, which was very weak in its indication.

38. The loci of the firing positions of an untreated submarine have been deduced, from the theoretical curves of Figures 1 and 2, and are given in Figures 9 and 10. While it was found impossible to verify these loci directly, because of the inaccuracies of distance measurements, there is no evidence to show that there were any serious deviations from the theoretical loci.

GENERAL ASSESSMENT

39. The general conclusion from the trials is that, while there are a number of sources of error, particularly in distance measurements, the fuzes operated satisfactorily with a sensitivity of about 10 milligauss. There is also strong evidence from the field curves to confirm that the firing of the fuze would occur close to the theoretical position.

40. Assuming the theoretical values and an explosive damage radius of projection of 40 feet to the hull, it is estimated that 90% of projectiles falling within a lateral range of 40 feet will fire within the damage range. This is equivalent to an effective lateral range of 35 feet. The effective lateral range for various explosive damage radii has been estimated and the results are plotted in Figure 11.

41. In preliminary attempts to compare the measurement of field with theory the results were presented in the form of contours in planer section through the hull, so that a direct comparison with the type of presentation given in A.U.W.E. Technical Note 90/62 could be made. Assuming that

distance measurements were correct the contours on a large number of trials did not make much sense. After allowing for distance errors by using magnetic methods of measuring distance, the contours became closer to the theoretical ones for an untreated submarine. There remained, however, a number of drops which could not be reconciled with theory assuming that the drops all occurred in one plane, and these were referred to as a "pinch" effect. The main discrepancy was that they appeared to come from a smaller object than expected in the particular plane. A likely explanation is that on the drops where the effect is pronounced the drop actually occurred some distance from the assumed plane of measurement, probably nearer to the end of the submarine where the section is smaller. This is confirmed in some cases by the fact that the shape of the curve on these drops on a southerly heading correspond more to that expected near the ends, i.e. they depart more from symmetry about the centre line of the submarine.

REFERENCES

1. Wood, J. E. Magnetic Field Calculations for an Anti-Submarine Proximity Fuze. A.U.W.E. Technical Note 90/62. August, 1962. (SECRET-DISCREET).

2. Abbott, D. A. Estimated Magnetic Field and Field Derivative Signatures for a Coastal Type Submarine, U.C.W.E. Informal Report No. 1649/55. (SECRET-DISCREET).

TABLE 1: ESTIMATED DISTANCES AND DEPTHS (FEET)

DISTANCES ARE FROM CENTRE LINE OF SUBMARINE

		HALFWAY TO STERN						CENTR			
HEADING SOUTH PORT	RUN NO.	20	22	24	26	27	28	8	9	16	
	NOMINAL DISTANCE	25	25	35	40	40	40	38	38	43	
	DISTANCE FROM SHAPE	36	38	30	49	43	52	38	53	48	
	DISTANCE FROM AMP.	30 C	29 C	36	40	48	42	32 C	32	56	
	NOMINAL DEPTH	110	110	110	110	110	110	110	110	110	
	DEPTH FROM CURVE	115	113	114	113	120	116	102	117	120	
HEADING EAST PORT	RUN NO.	124	125	126	127	128		118	119	120	1
	NOMINAL DISTANCE	15	15	25	25	35		28	38	38	
	DISTANCE FROM SHAPE	34	31	49	55	51		32	46	41	
	DISTANCE FROM AMP.	30 C	30 C	40	43	45		32	43	39	
	NOMINAL DEPTH	110	110	110	110	110		110	110	110	1
	DEPTH FROM CURVE	100	100	98	100	96		100	107	102	1
HEADING EAST STARBOARD	RUN NO.	57	58	59	60	61	62	63	64	65	
	NOMINAL DISTANCE	25	25	35	35	40	40	18	18	28	
	DISTANCE FROM SHAPE	67	57	87		80		66	72	74	
	DISTANCE FROM AMP.	48	49	50	57	62	70	61	69	74	
	NOMINAL DEPTH	110	110	110	110	110	110	110	110	110	
	DEPTH FROM CURVE	128	120	120		115		120	117	125	

C SIGNALS CLIPPED

1

E 1: ESTIMATED DISTANCES AND DEPTHS (FEET)

HALFWAY TO STERN					CENTRE						HALFWAY TO BOW					
22	24	26	27	28	8	9	16				32					
25	35	40	40	40	38	38	43				25					
38	30	49	43	52	38	53	48				50					
29	36	40	48	42	32	32	56				60					
C					C											
110	110	110	110	110	110	110	110				110					
113	114	113	120	116	102	117	120				95					
125	126	127	128		118	119	120	121	122	123	109	110	111	112	113	114
15	25	25	35		28	38	38	38	43	43	25	25	35	35	40	40
31	49	55	51		32	46	41	39	45	41	35	37	46	51	70	61
30	40	43	45		32	43	39	34	43	3[illegible]	31	29	44	47	55	60
C																
110	110	110	110		110	110	110	110	110	110	110	110	110	110	110	110
100	98	100	96		100	107	102	102	104	102	105	107	100	98	102	102
58	59	60	61	62	63	64	65				71	74	76			
25	35	35	40	40	18	18	28				15	15	25			
57	87		80		66	72	74				51	57	65			
49	50	57	62	70	61	69	74				48	58	48			
110	110	110	110	110	110	110	110				110	110	110			
120	120		115		120	117	125				124	126	120			

2

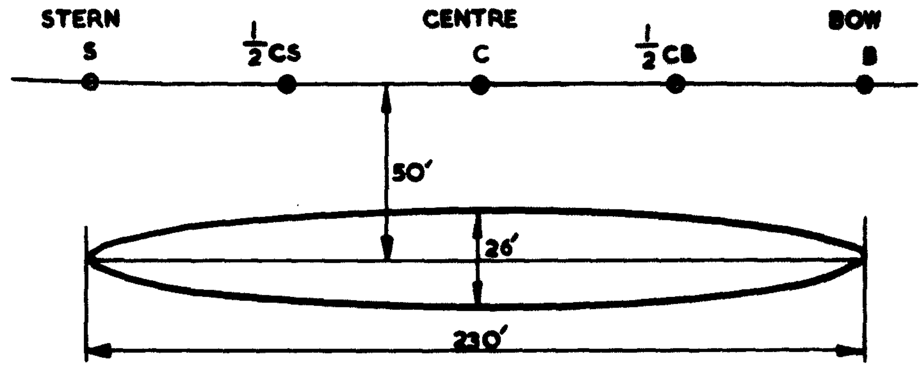


FIG.1. DROP POSITIONS FOR THEORETICAL CURVES.

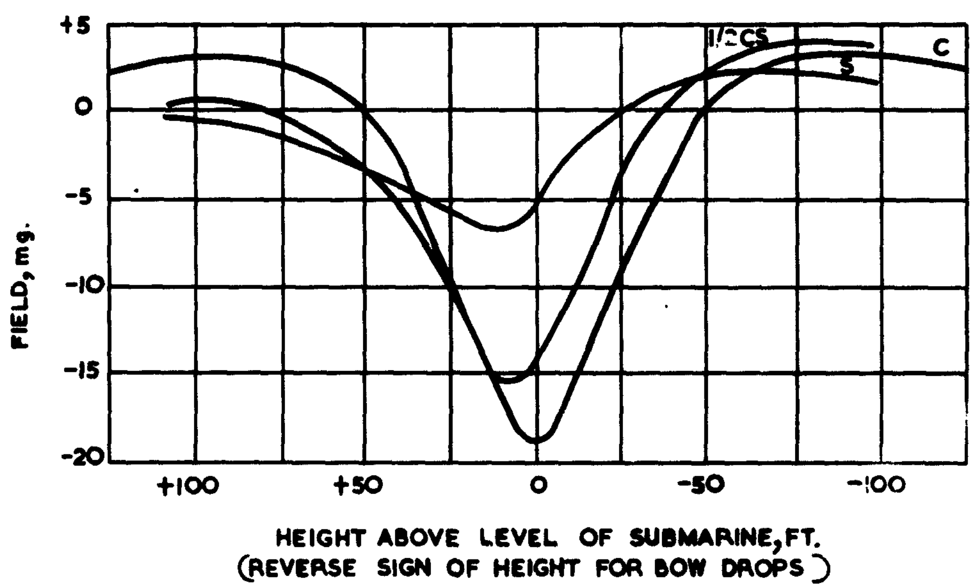


FIG.2. THEORETICAL FIELD SIGNALS AT 50 FEET ON EITHER SIDE OF SUBMARINE HEADING SOUTH (70° DIP)

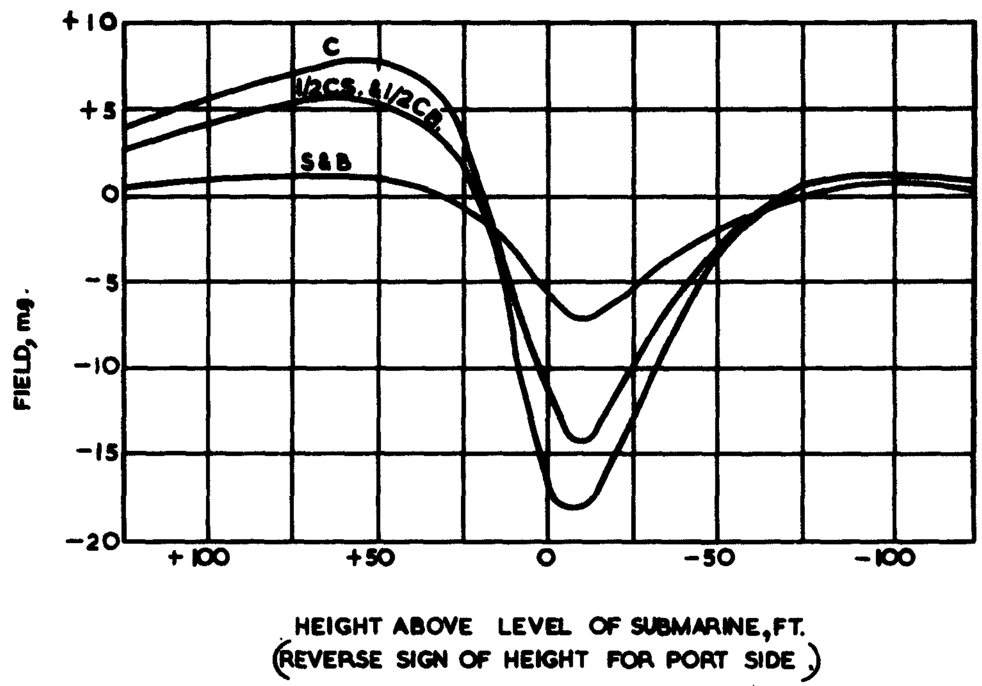
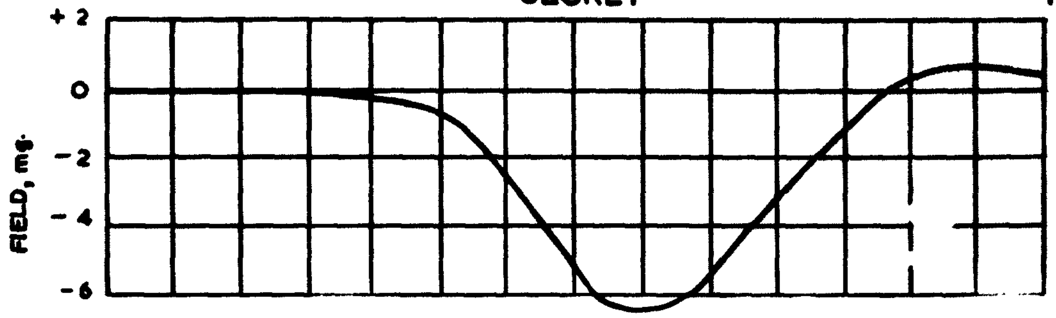
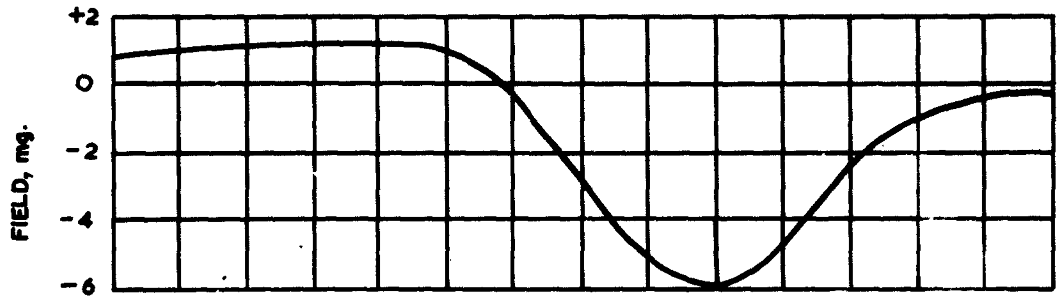


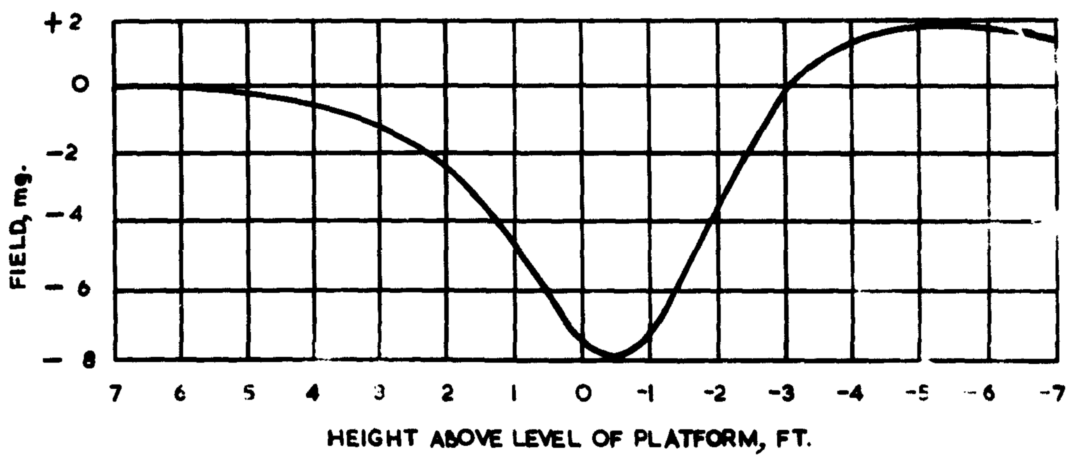
FIG.3. THEORETICAL FIELD SIGNALS AT 50 FEET ON THE STARBOARD SIDE OF SUBMARINE HEADING EAST (70°DIP).



(A) PORT SIDE FOR SUBMARINE HEADING SOUTH



(B) PORT SIDE FOR SUBMARINE HEADING EAST



(C) STARBOARD SIDE FOR SUBMARINE HEADING EAST

FIG. 4. MEASURED VALUES OF ANOMALY FIELD.

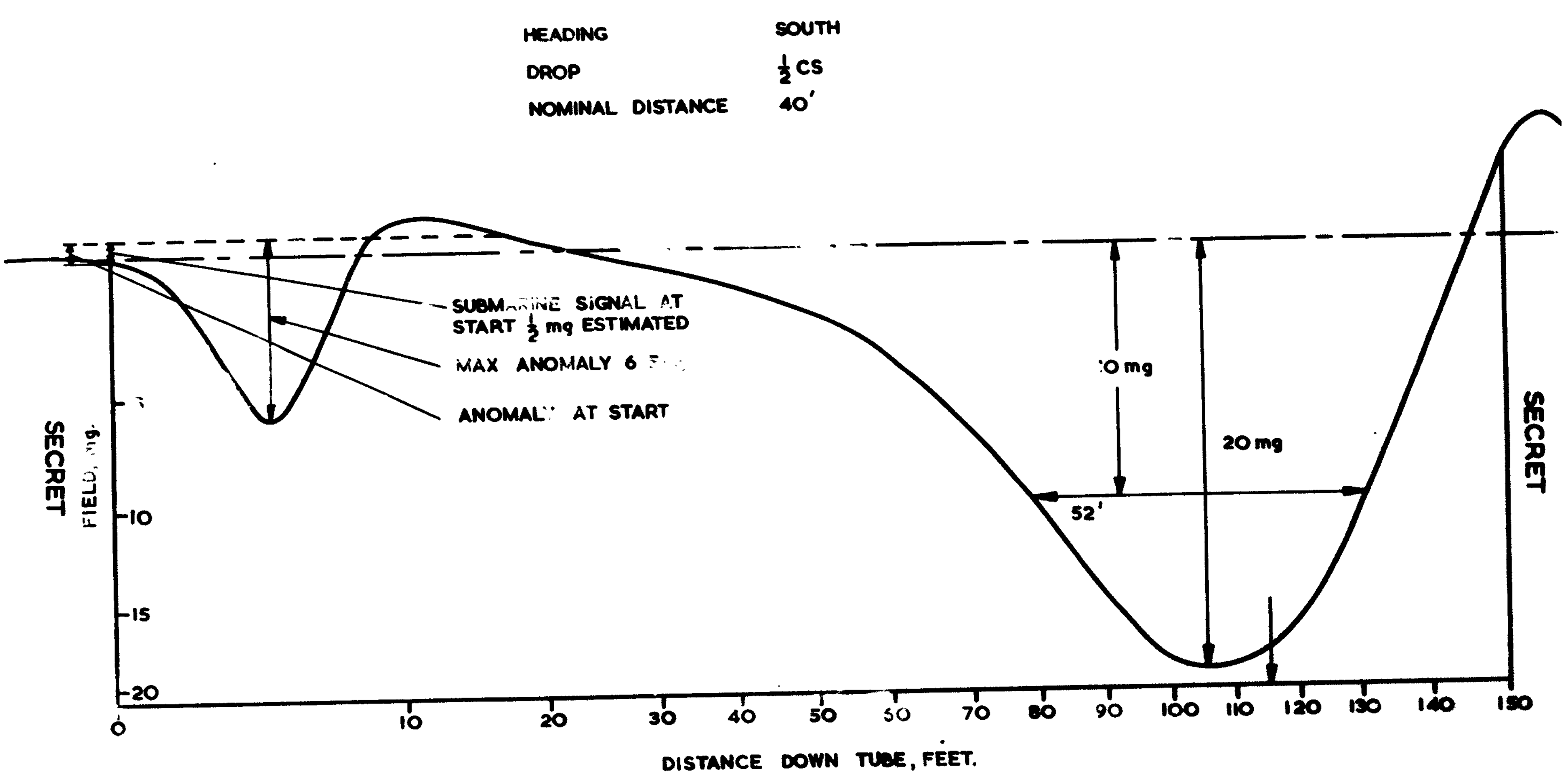


FIG.5. RUN 28, TYPICAL GOOD RECORDING.

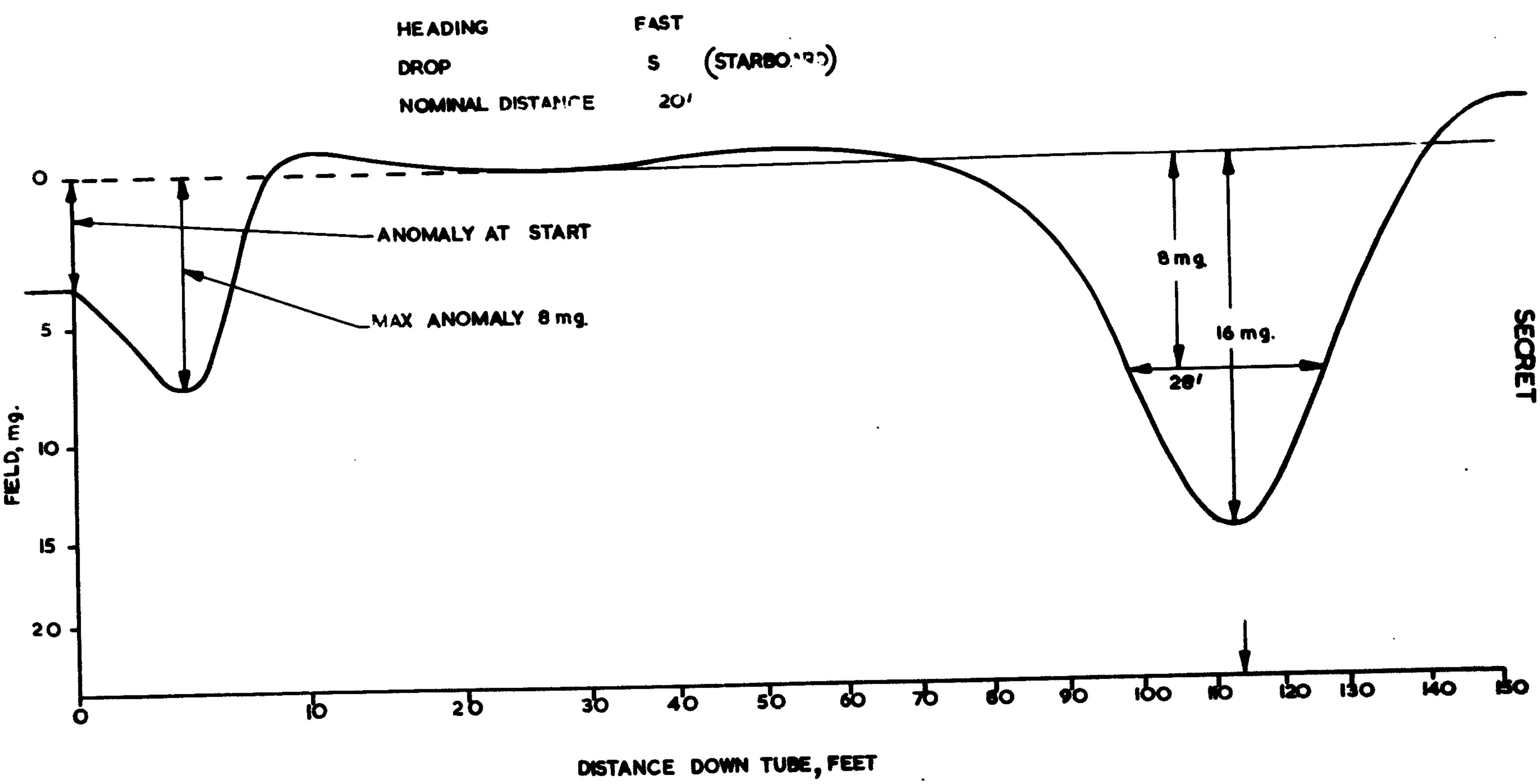


FIG. 6. RUN 94, GOOD RECORDING NEAR STERN.

SECRET

SECRET

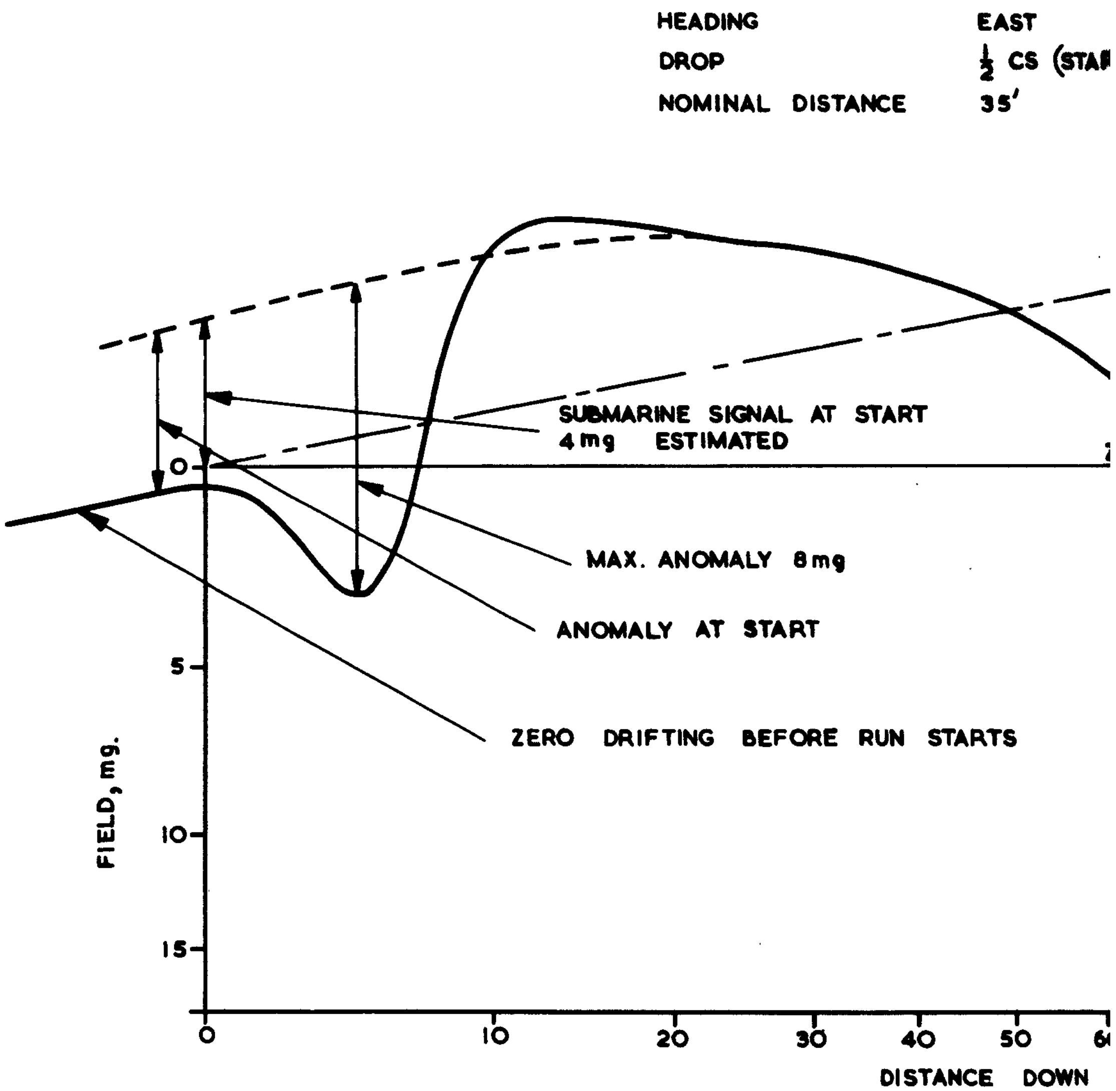
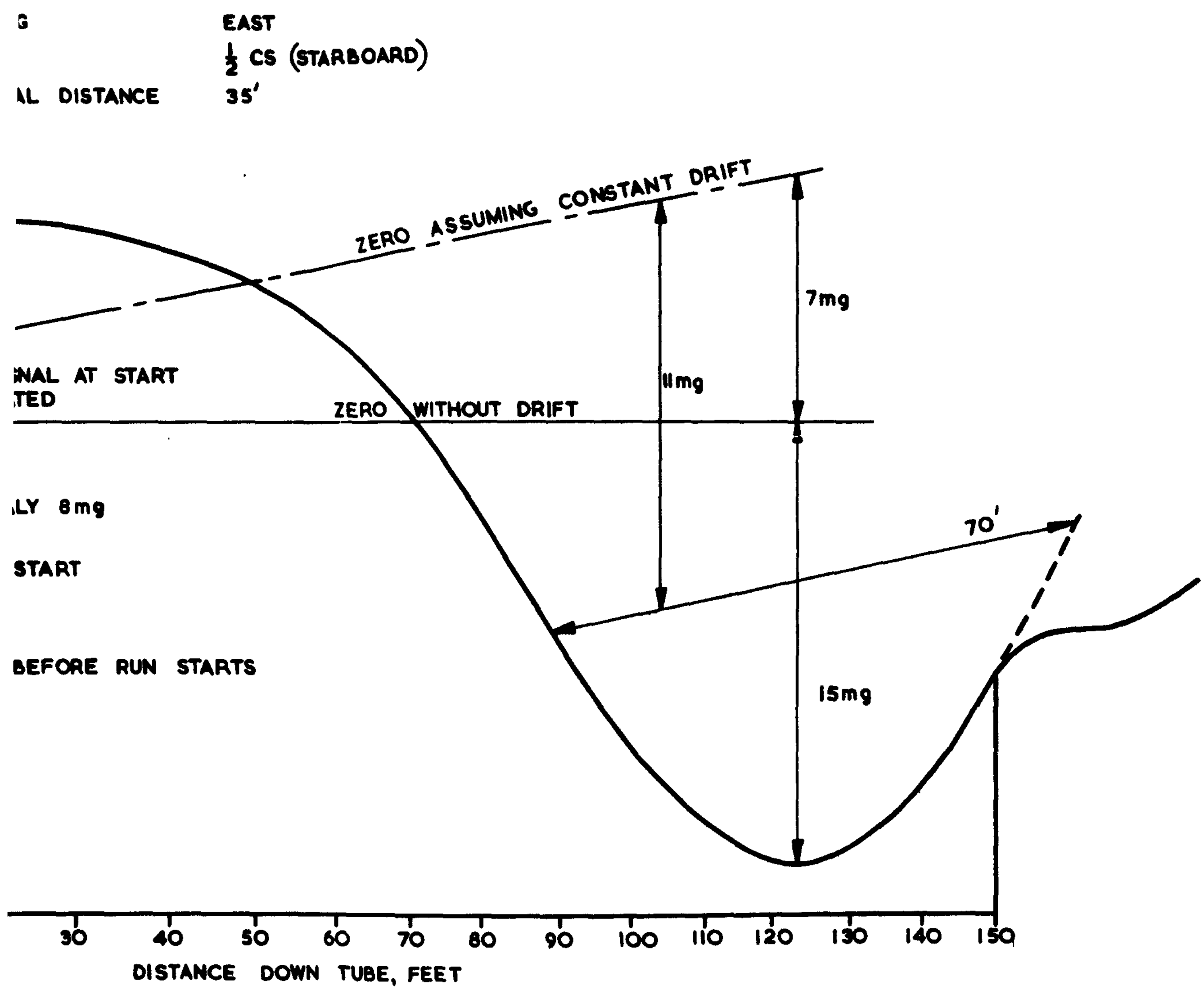


FIG. 7. RUN 59, ILLUSTRATING EF

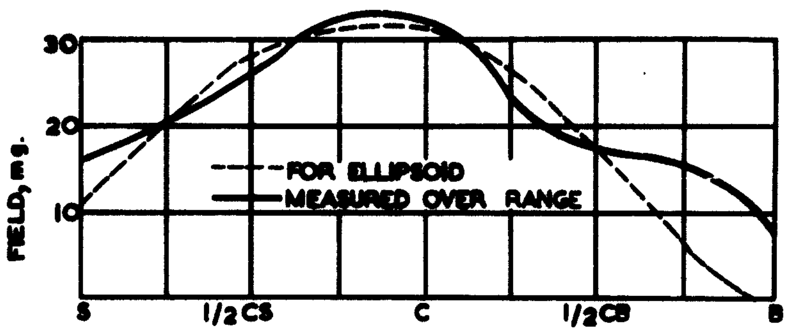
1

FIG. 7.

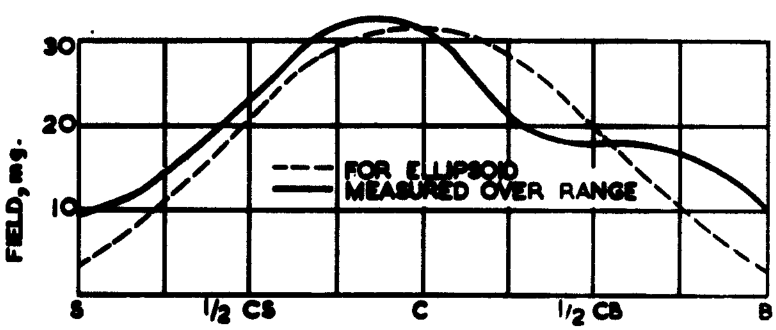


59, ILLUSTRATING EFFECT OF AMPLIFIER DRIFT.

2



(a) SUBMARINE HEADING SOUTH.



(b) SUBMARINE HEADING EAST.

FIG.8 FIELD 45 FEET BELOW CENTRE-LINE OF SUBMARINE.

FIG. 9.

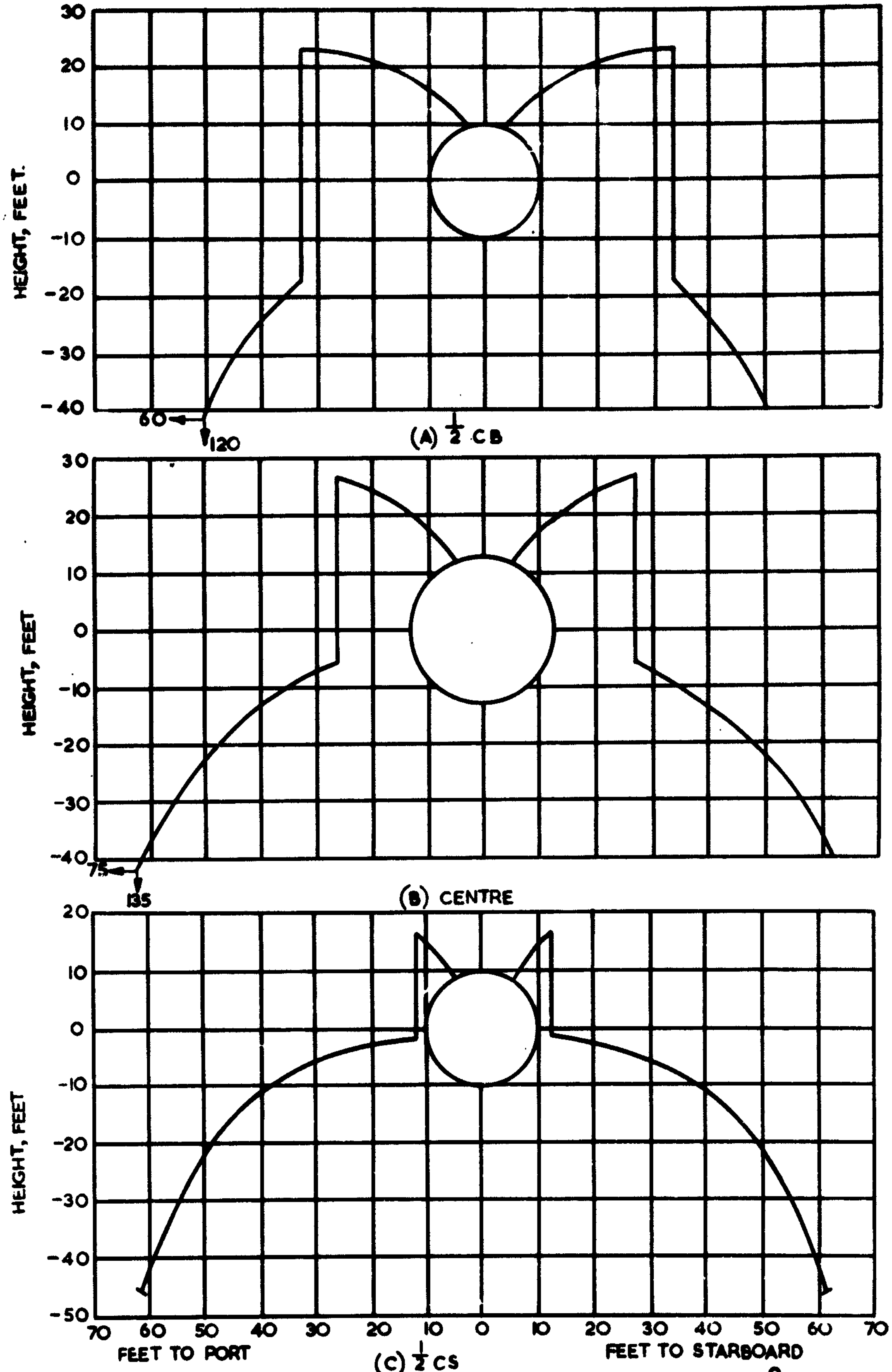
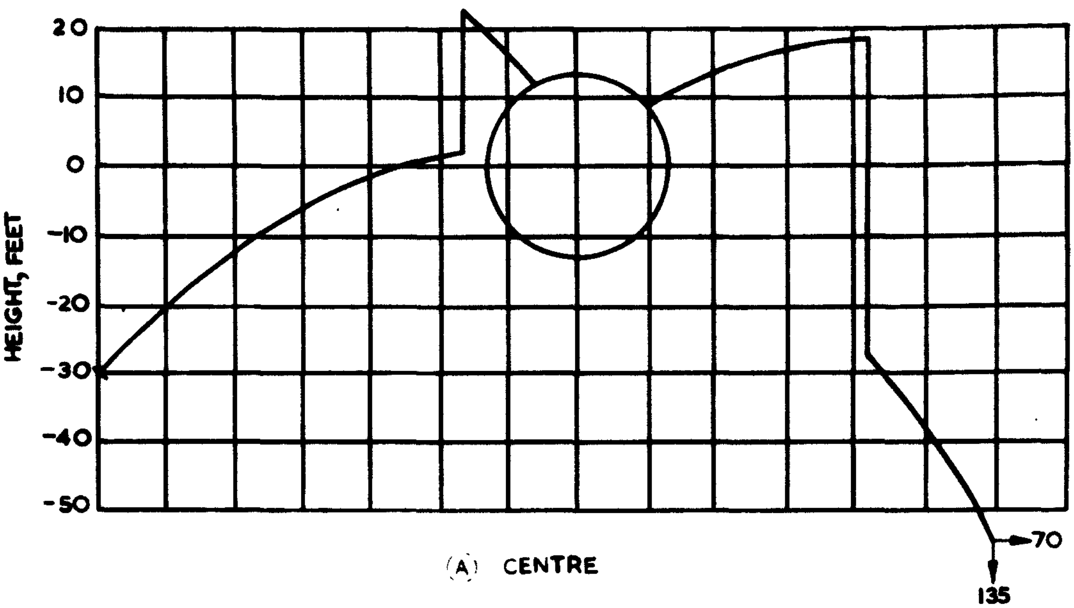
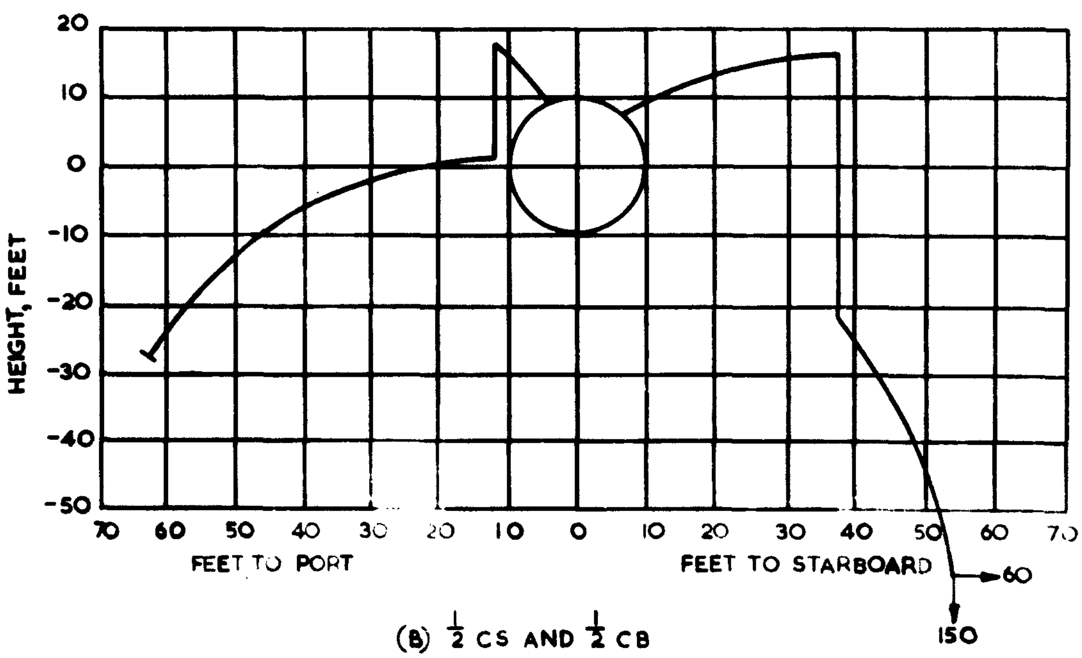


FIG. 9 FIRING LOCI FOR SUBMARINE HEADING SOUTH (70° DIP)
(REVERSE BOW AND STERN FOR NORTH HEADING)



(A) CENTRE



(B) $\frac{1}{2}$ CS AND $\frac{1}{2}$ CB

FIG. 10 FIRING LOCI FOR SUBMARINE HEADING EAST (70° DIP)
(REVERSE PORT AND STARBOARD FOR WEST HEADING)

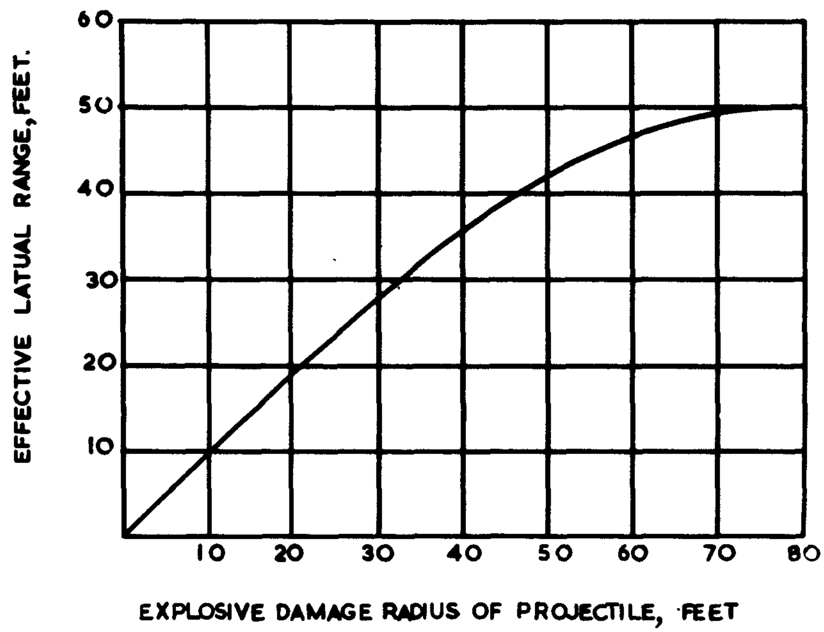


FIG. 11. EFFECTIVE DAMAGE RANGES.

U.K. ABSTRACT
NO. ________

(A)	Country of Origin	UNITED KINGDOM.
(B)	Establishment of origin with short address	Admiralty Underwater Weapons Establishment, Portland.
(C)	Title of Report	Analysis of Canadian Trials of the Proximity Fuze for Project Insight.
(D)	Author	A. Butterworth.
(E)	Pages and Figures	11 pages ((i) - (ii) (1 - 9)) Figs. 11.
(F)	Date	April, 1964.
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(J)	Abstract	This report is a critical analysis of full scale trials in Scottish waters of the magnetic influence fuze designed for Project Insight. The trials, which were performed by the Canadians with A.U.W.E. support, were against a submarine first in its natural stable magnetic condition and then in a wiped condition. In addition to testing the operation of the fuze, the magnetic field round the submarine was investigated and compared with theory.

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